BTeV RICH
Design and Status of Development

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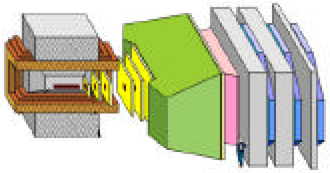
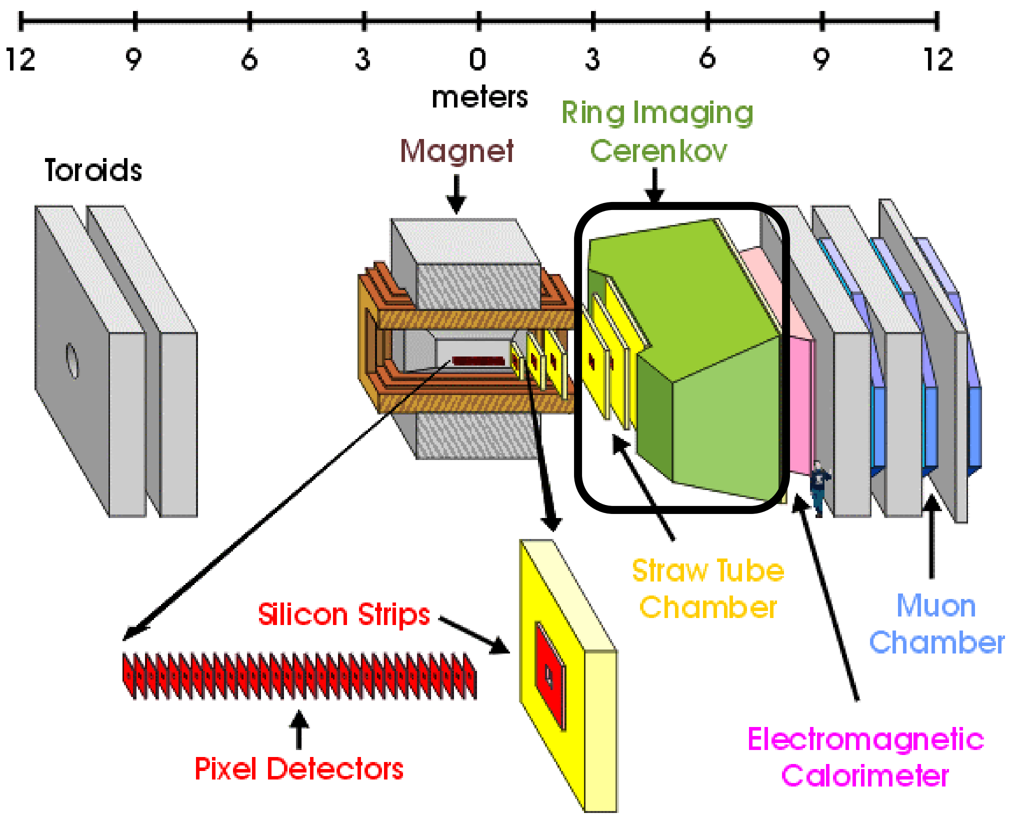
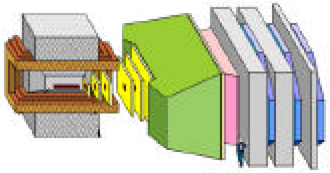
Fermilab



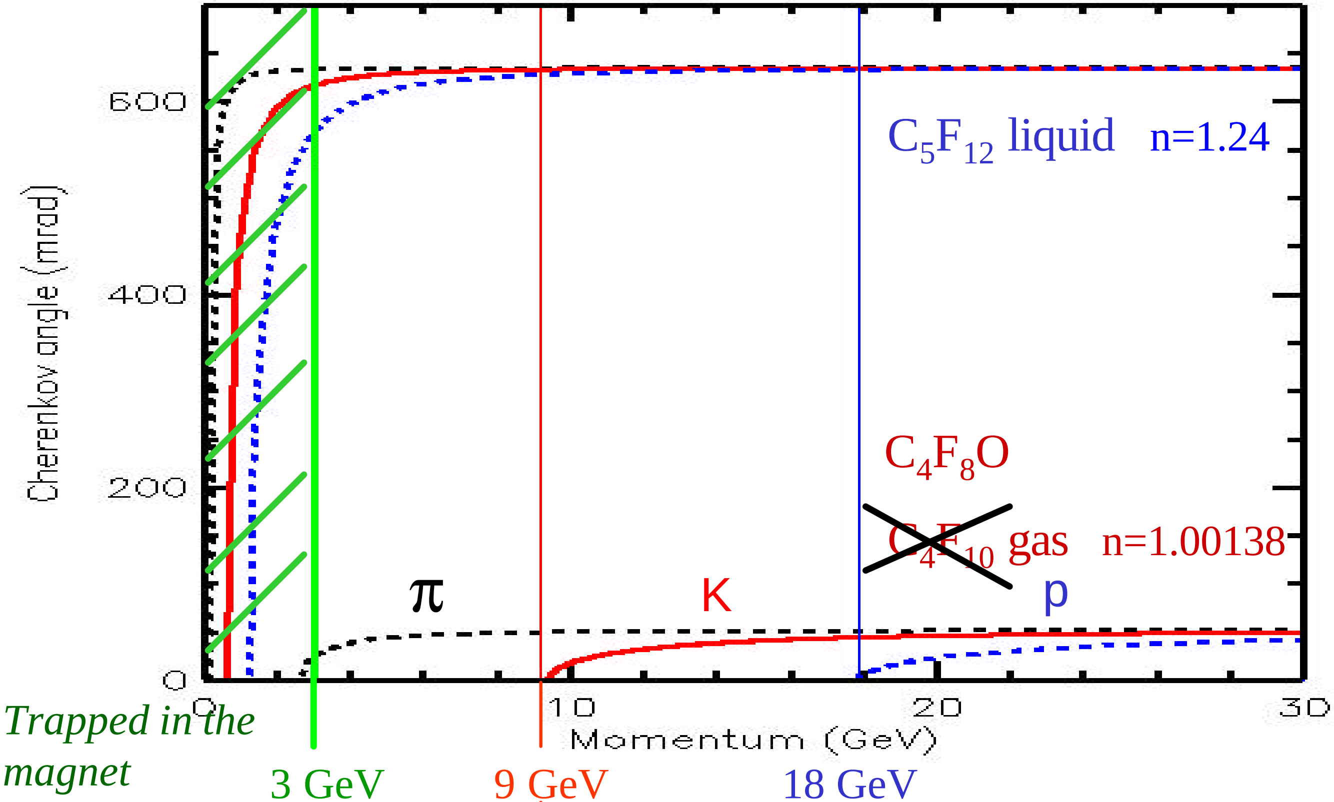
The BTeV Detector



- Particle identification is absolutely essential in flavor physics experiments
- Lepton Identification:
  - Electrons: Electromagnetic Calorimeter
  - Muons: Muon Chambers
- Hadron Identification:
  - π/K/p: RICH (p ~ 3-70 GeV)
- RICH will also extend the lepton identification at low momenta beyond the aperture of the calorimeter and muon chambers



Choice of Cherenkov Radiators



Secondary radiator:
*The smallest **n** among liquid radiators*

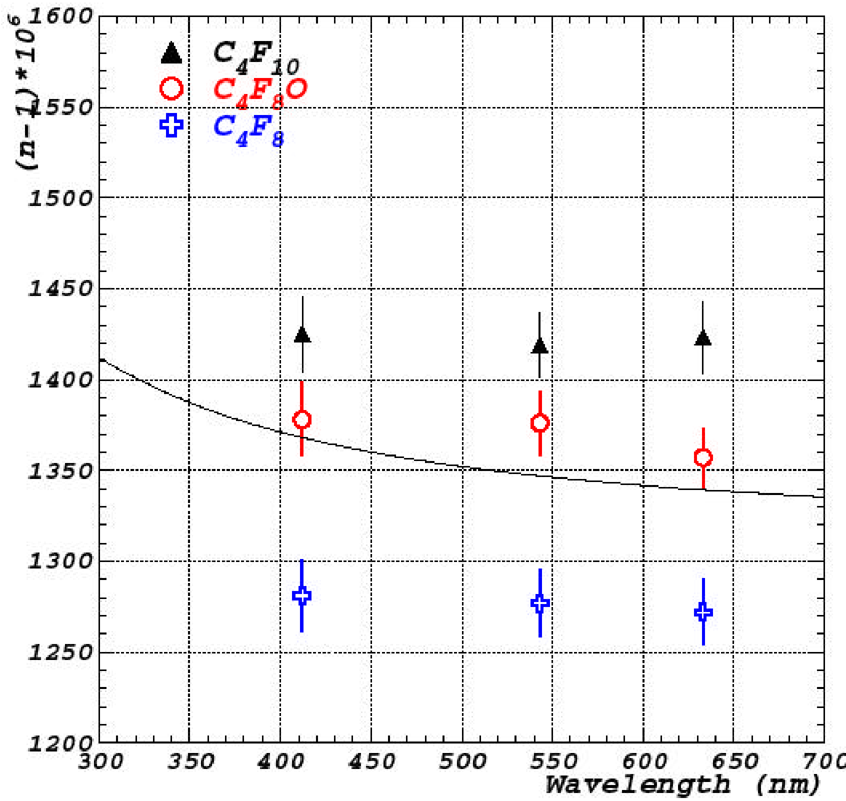
Primary radiator:
*The largest **n** among RTP gas radiators*

No K/p separation below 9 GeV in the gas! ↦ need 2nd radiator

Production of C_4F_{10} has been discontinued by 3M. Stockpiles exists but prices have gone up and long-term availability is highly questionable.

C_4F_8O in use by semiconductor industry (for plasma etching and cleaning CVD chambers) since 1999.
First use as Cherenkov radiator.

Measurements of refraction indices of fluorocarbons in visible wavelengths

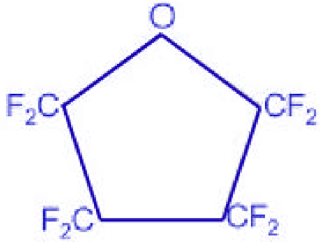


Using lasers and Michelson Interferometry

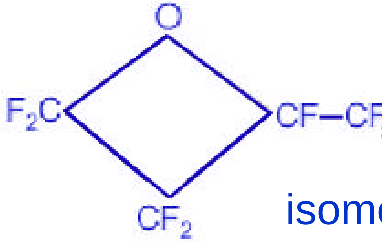
Previously used in our simulations

- The RICH prototype test beam data with C_4F_8O give consistent results (discuss this later in my talk)

Other properties of C_4F_8O



- *Chemical name:* octafluorotetrahydrofuran.
- *Density:* ~10 times heavier than air: 0.58 lb/ft^3 at 20^{o}C (1.52g/mL as liquid)
- *Boiling point:* –0.8^{o}C (Matheson TRI-GAS MSDS), -5.5^{o}C (American Chemical Society) . *Break-up point:* 225^{o}C
- Not a poison. Non-explosive. Colorless. Odorless.
- Stable, mostly non-reactive except with alkali halide metals (Sodium, Potassium)
- According to manufacturer can pick-up and transport oils. Contact with organic materials should be minimized.
- Produced by 3M, distributed e.g. by Praxair
  - 99.6% pure, rest mostly the isomer of this molecule, also other perfluorocarbons (freons)
  - Non-perfluorocarbons <0.05%
- Price: ~\$40/lb (\$24/ft^3 at 20^{o}C)



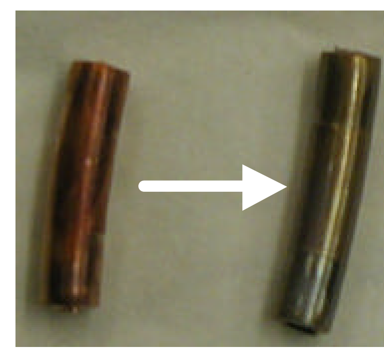
isomer

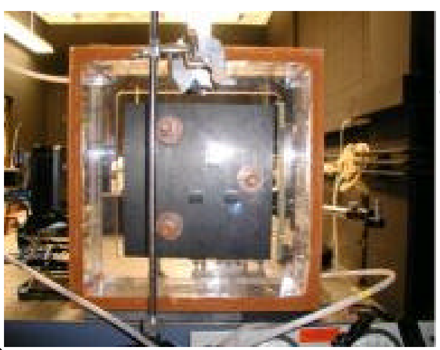
Material compatibility tests

Material compatibility tests with C_4F_8O in progress at Syracuse.

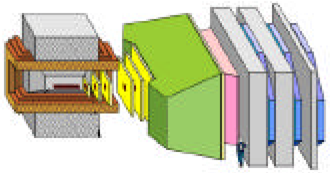
Samples of materials exposed to C_4F_8O. Inspect physical properties of samples and analyze gas with chromatograph and proton NMR.

The only effect observed so far - discoloration of copper pipe after exposure equivalent to 0.5-4.0 years at room temperature





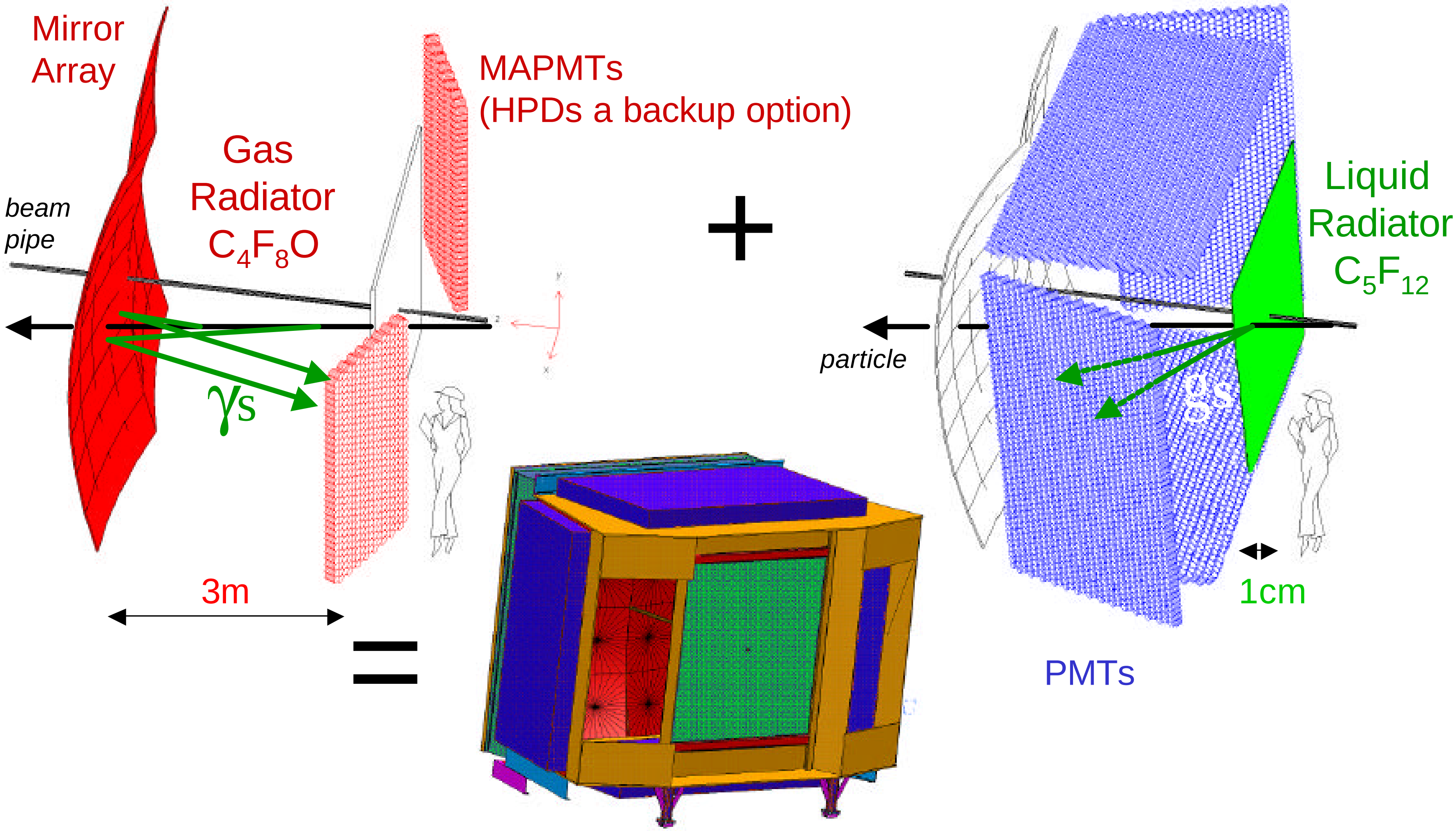
CMA CF mirror inside transparent box with C_4F_8O.
Monitor mirror optical properties.



RICH Components

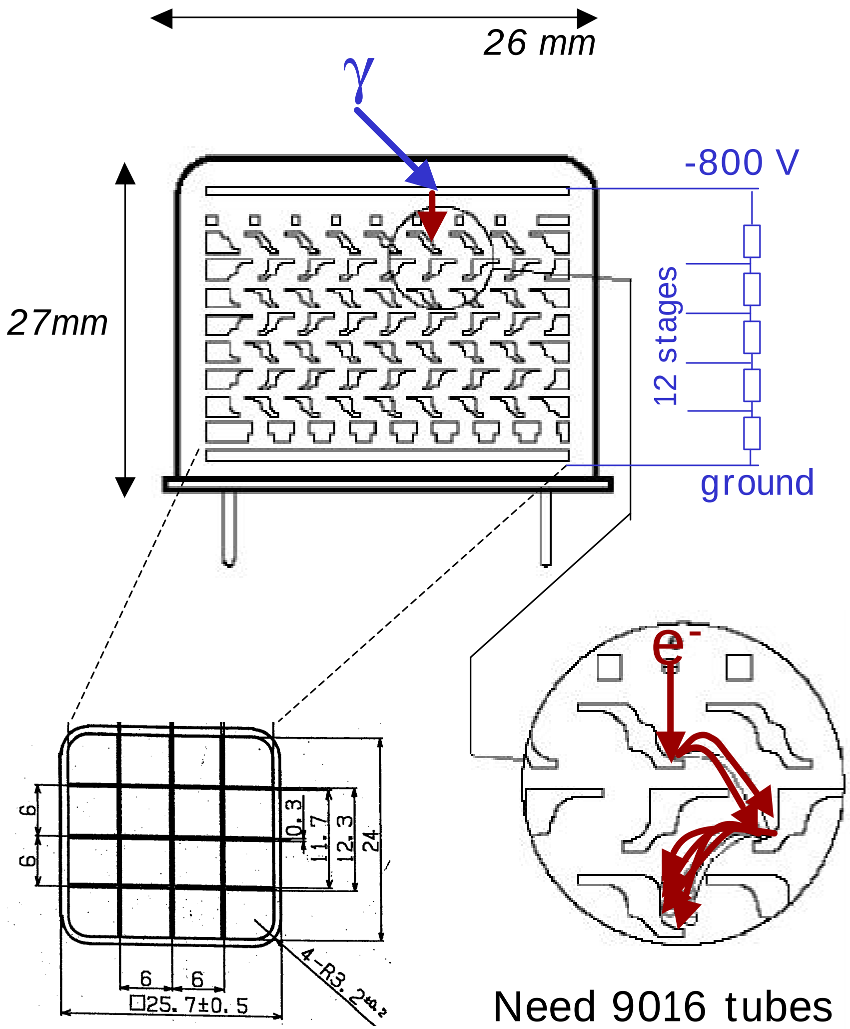
Mirror Focused Gas Radiator RICH

Proximity Focused Liquid Radiator RICH



Complete spatial separation of Cherenkov photons from the two radiators

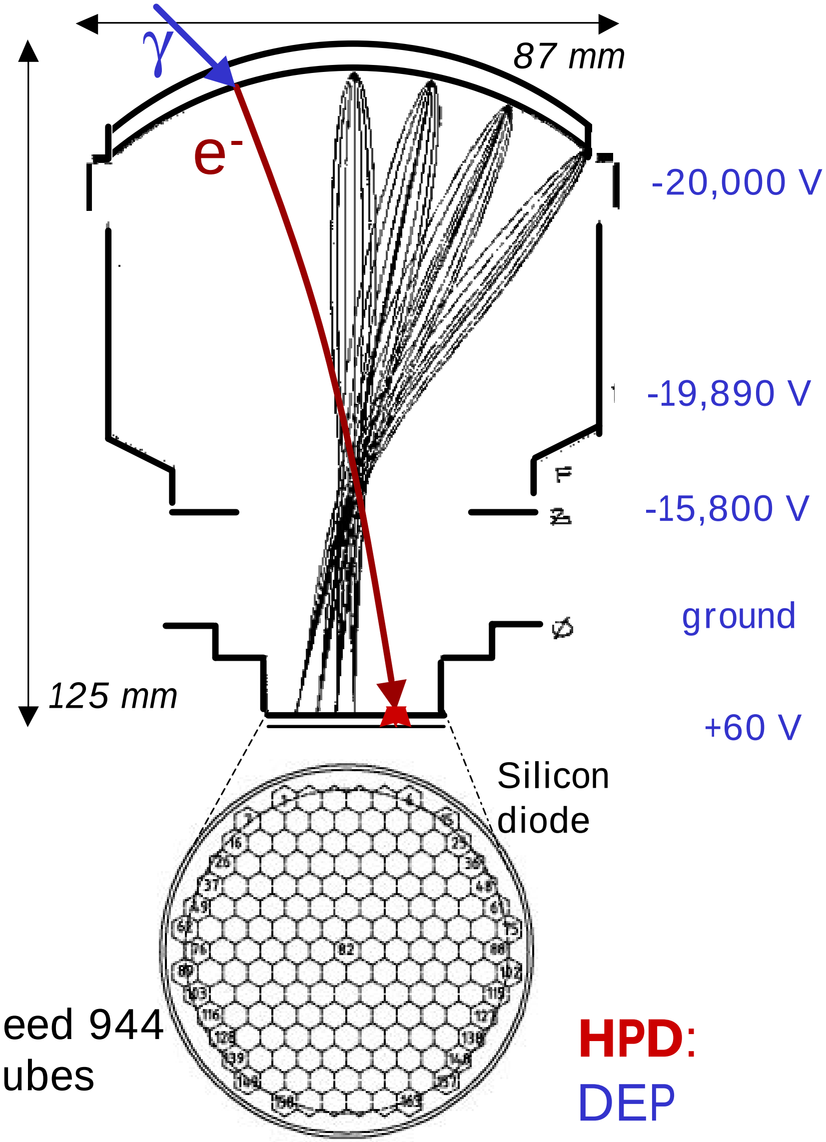
Photodetector options for the gas RICH



Need 9016 tubes

MAPMT: Hamamatsu R8900-M16

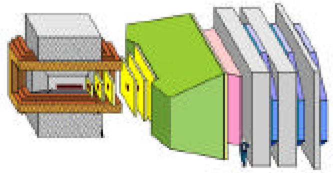
baseline



Need 944 tubes

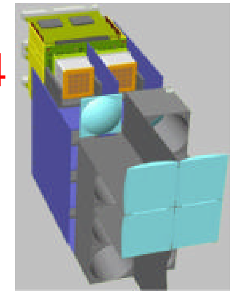
HPD:
DEP
PP0380AT

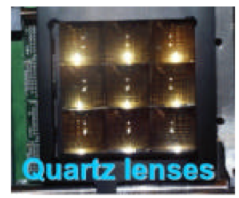
backup

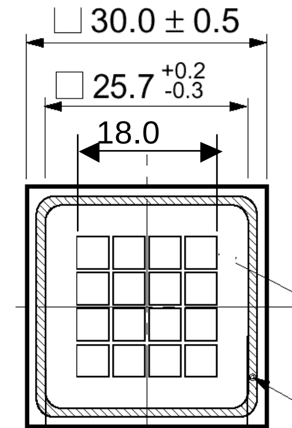


Hamamatsu MAPMTs

- First used in RICH detector by HERA-b (since 1998)
  - 1488 R5900-M16 + 752 R5900-M4
  - Active area: 36%
  - Double-lens focusing system
- Improved version with increased segmentation tested by LHC-b
  - R7600-M64
  - Active area: 48%
  - Single convex-plano lens system increases geometrical efficiency to 74%
- Redesigned focusing scheme on the first dynode
  - R8900-M16
  - Active area: 85%
  - No lens system needed!
  - **6x6 mm pixel size well suited for BTeV**
  - R8900-M25 developed for EUSO telescope



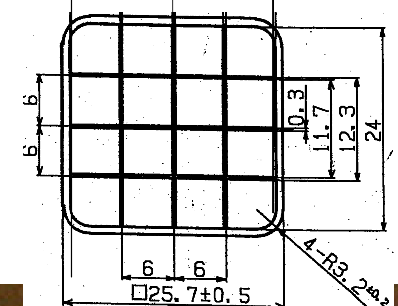




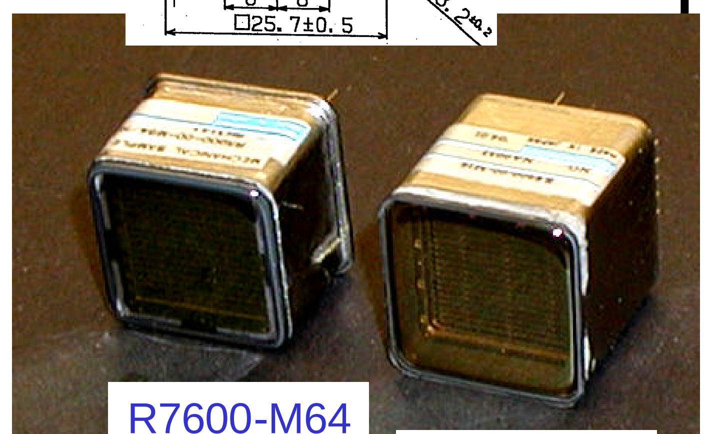
R5900-M16

R7600-M64: no outer insulating layer

FILLED WITH INSULATOR



R8900-M16

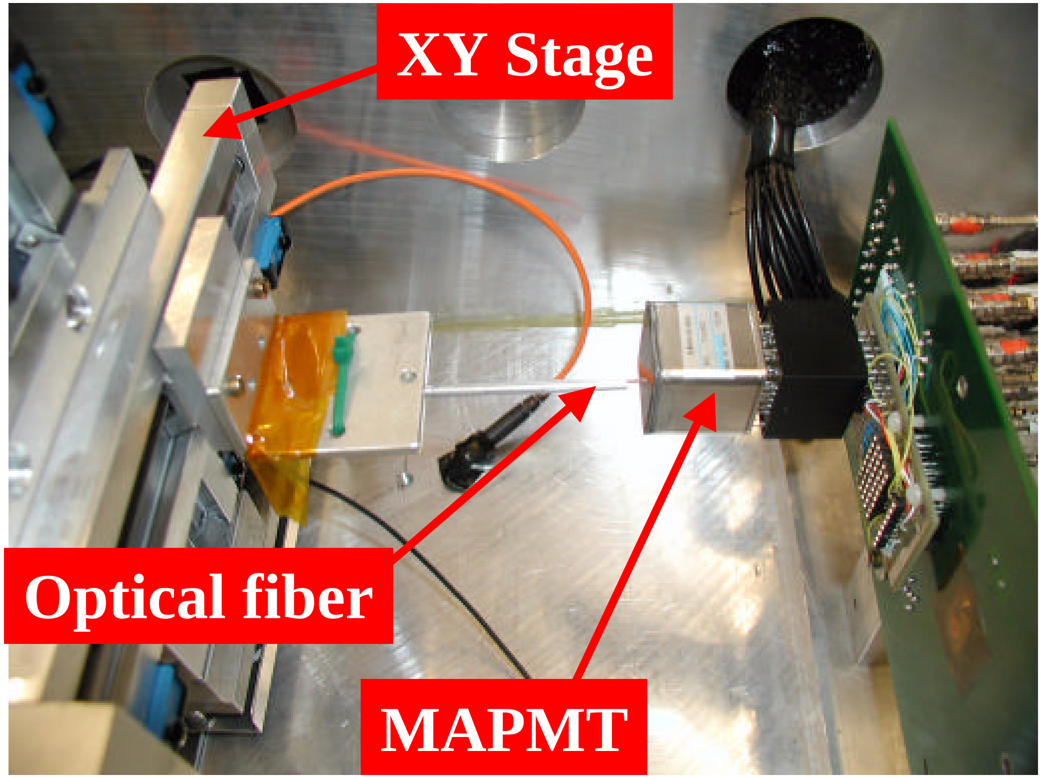


R7600-M64

R8900-M16

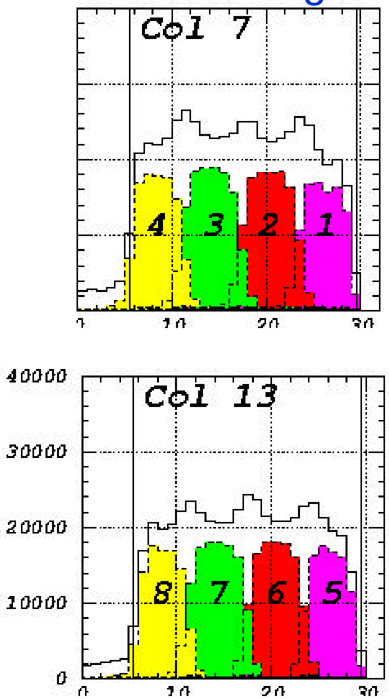
R8900-M16 tests at Syracuse

- 2 prototypes studied on a bench in 2002-03
- 52 improved R8900-M16s received and tested in 2004
  - Characterized on a bench
  - Used in test beam at FNAL in June 2004



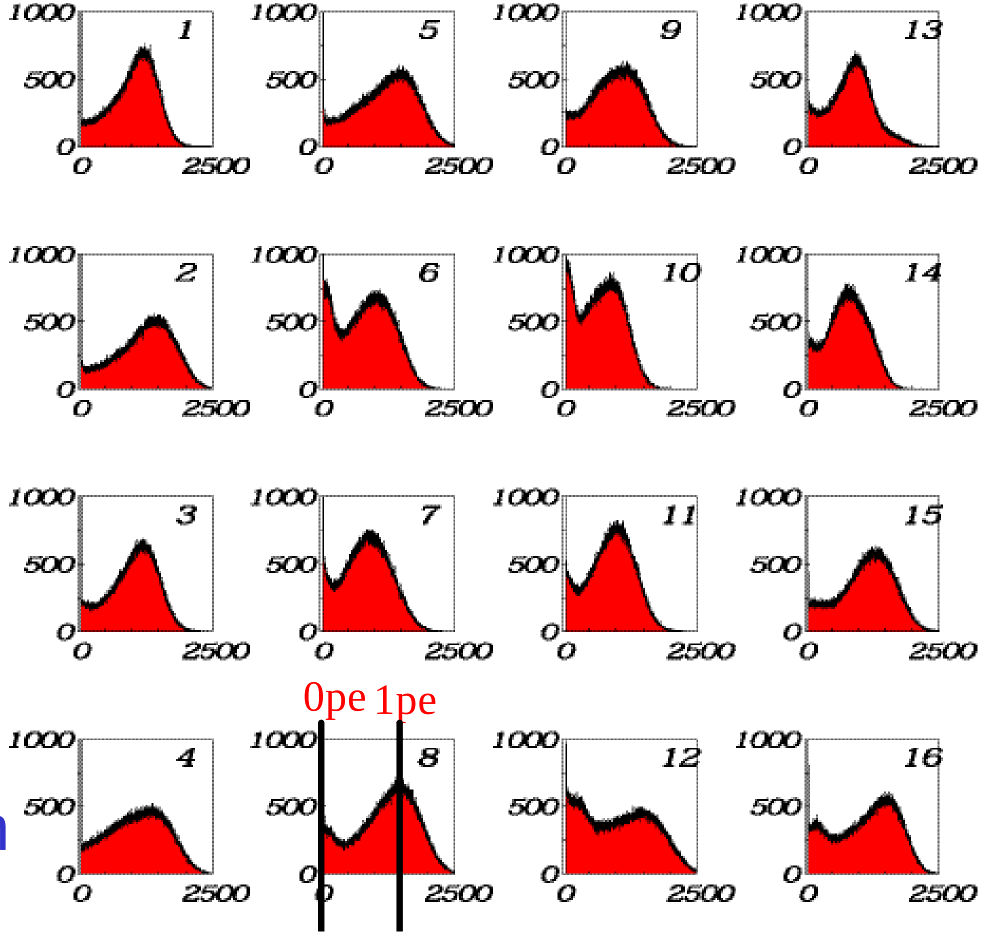
Bench Tests of R8900-M16

Photon counting rate



cross-talk σ ~0.5mm

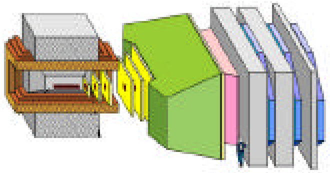
MAPMT R8900-M16



~1,000,000e

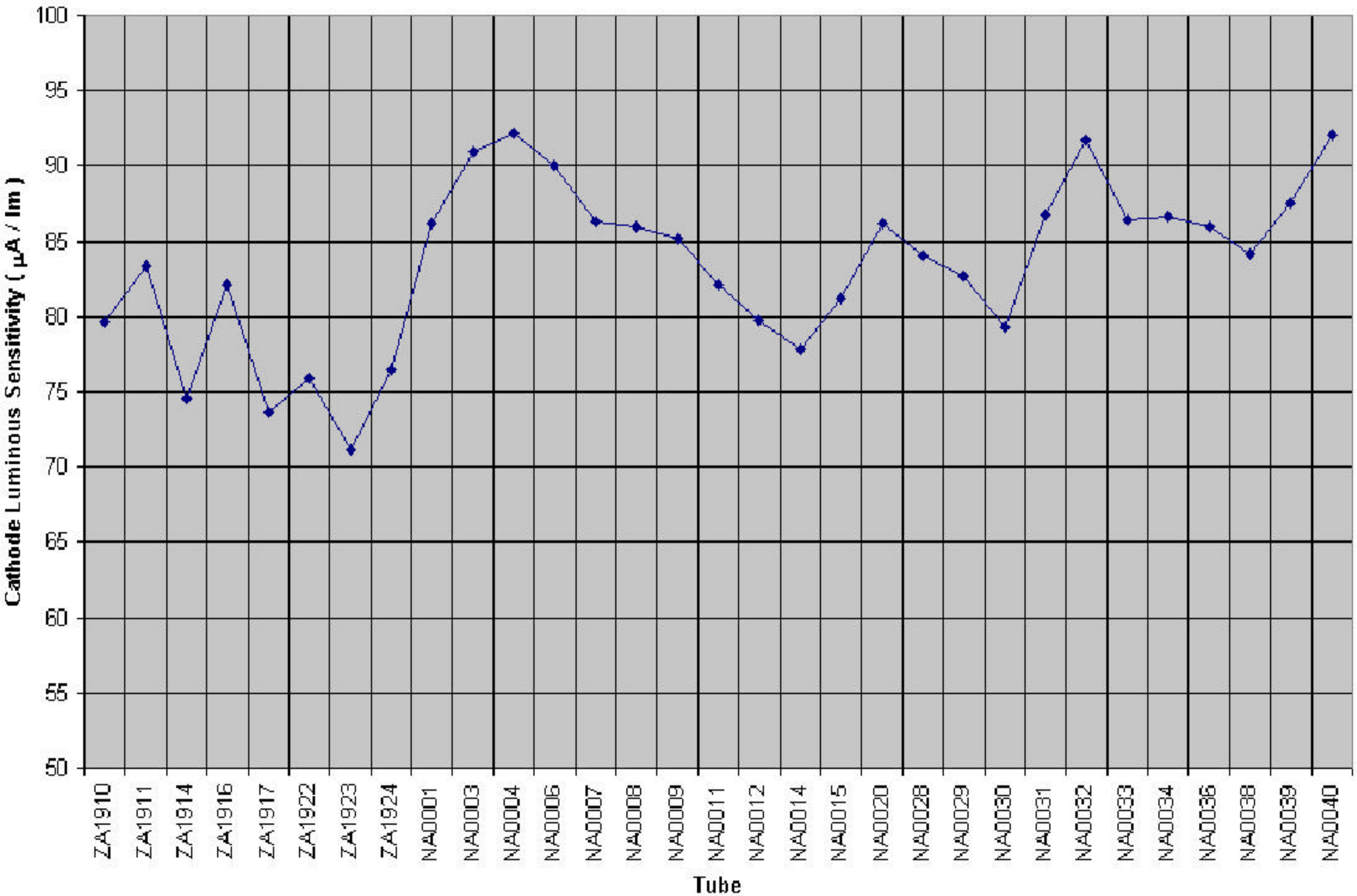
Expected ENC =2,000 e

Pulse-height for various pixels obtained with analog readout



R8900-M16 Cathode Luminous Sensitivity

- Sensitive to Quantum Efficiency. Measured by Hamamatsu for tubes sent to Syracuse:



"Typical"

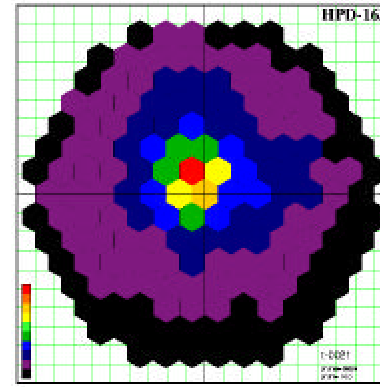
"Minimal"

in Hamamatsu MAPMT data sheets

DEP HPDs

- Initial cross-focusing 61 pixel HPD
  - Active area: 80% * 91% (packing) = 73%
  - 61 pixels/tube – too few for LHC-b and BTeV
- LHC-b/ALICE development:
  - Needed 2.5mm pixel size – 1024 (8182) pixels/tube
  - Fast readout (25ns, 40MHz)
  - Readout chip integrated with the silicon diode, sealed inside HPD
  - Chosen for LHC-b baseline
- BTeV development:
  - 163 pixels/tube – 5.7mm pixel size (hex)
  - Bunch crossing: 396ns
  - Readout chip attached externally
  - Added potting with insulator for operations in magnetic shield (decreased active area to 66%)

Counting Rate vs pixel position for light injected with a fiber

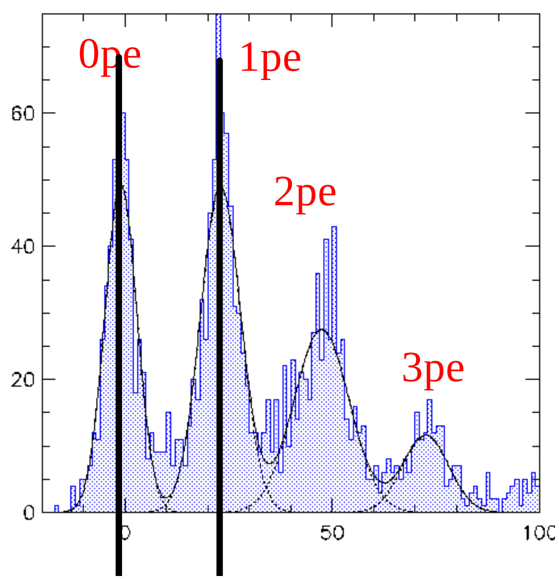


(Variation in counting rate reflects the light intensity profile)

Bench Tests of PP0380AT HPDs

- 2 prototypes studied on a bench in 2001-02
- 15 potted PP0380AT HPDs received from DEP
  - Fully characterized with analog readout:
    - No dead channels

BTeV HPD readout with VA_RICH

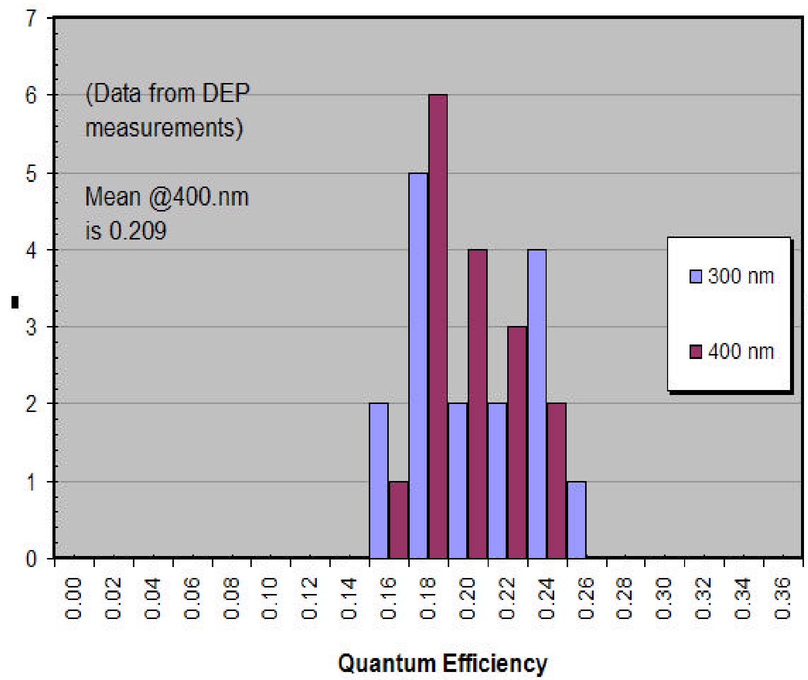


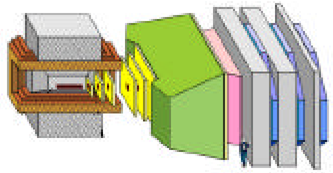
~5,000e

Expected ENC =500 e

Quantum Efficiency

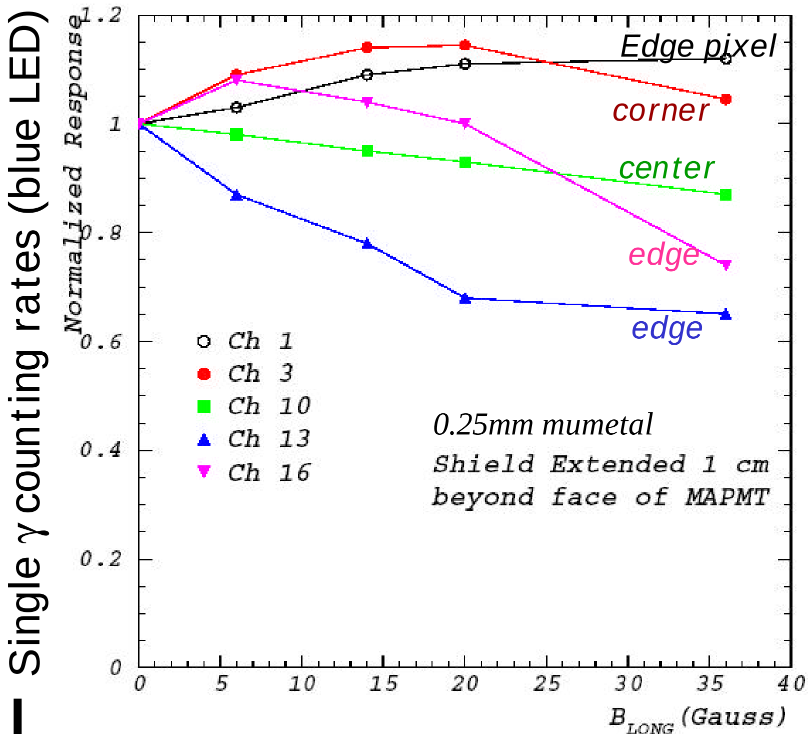
measured by DEP for tubes sent to Syracuse





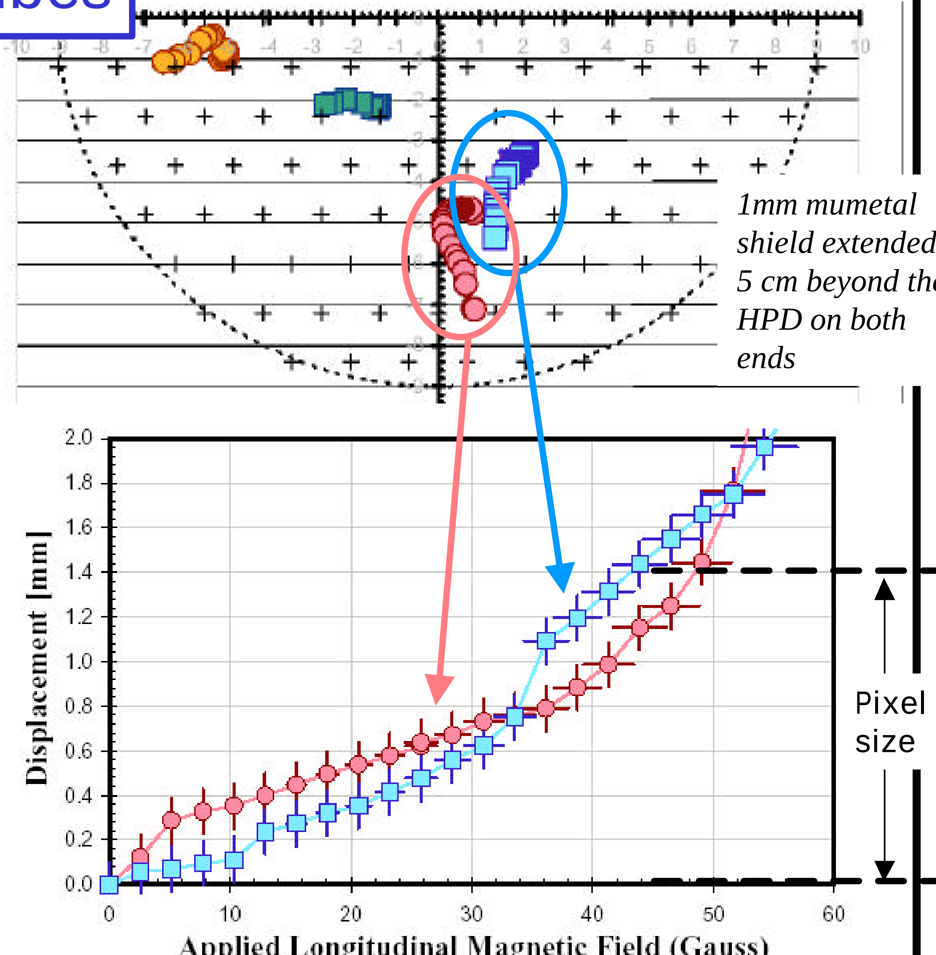
MAPMT vs HPD: magnetic field sensitivity

Shielded tubes



MAPMT

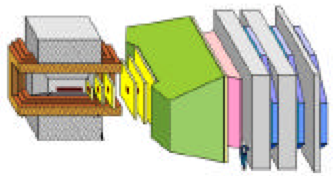
Loss (or improvement) of counting efficiency



HPD

Hit displacement (image distortion)

Require B_L<10 Gauss



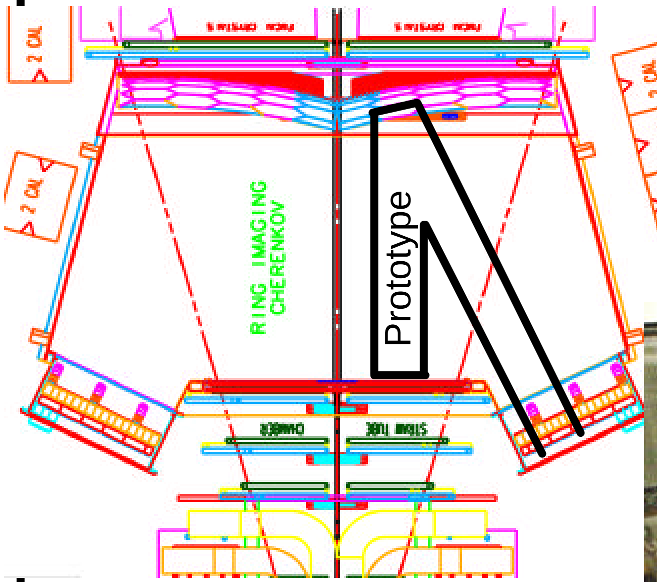
MAPMT vs HPD: expected performance

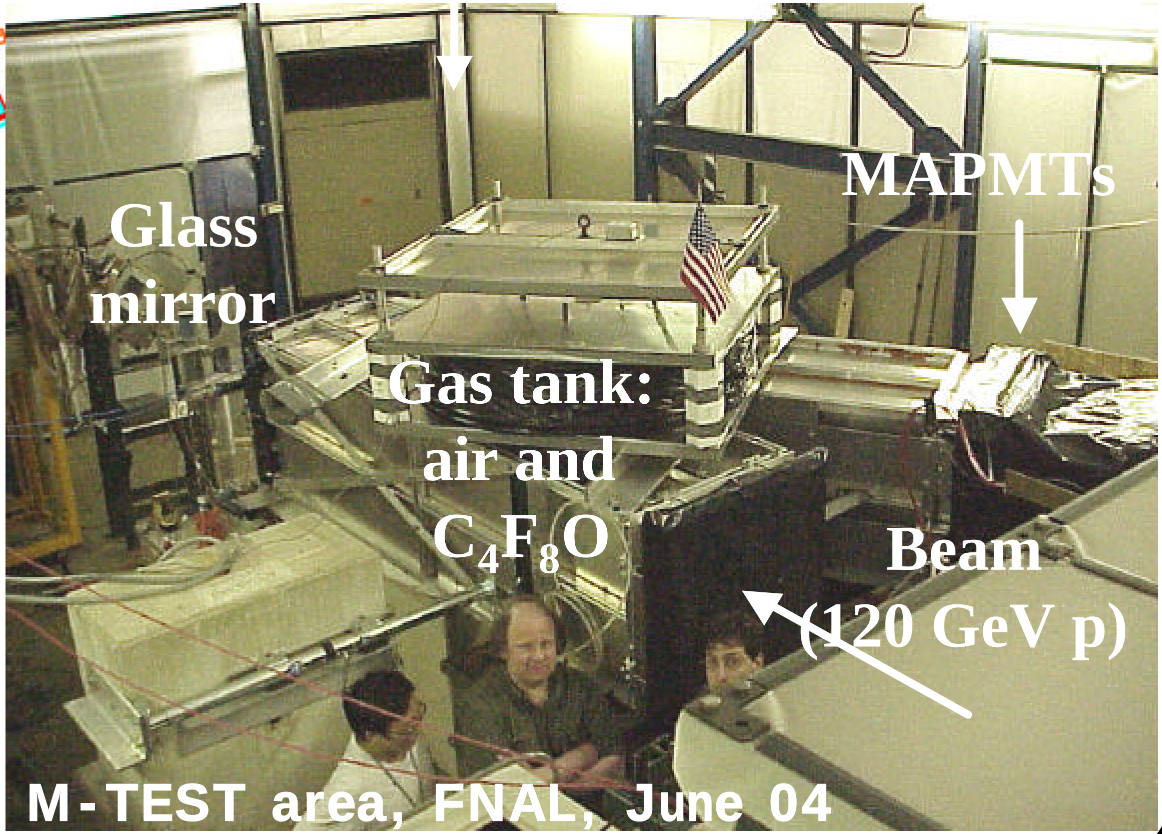
(UVT acrylic window in front of the photodetectors: λ>270 nm)

Photon detector	MAPMT	HPD
Emission point error	0.49 mrad	
Segmentation error	0.51 mrad	0.45 mrad
Chromatic error	0.44 mrad	0.52 mrad
Total s$_{q}$ per photon	**0.83 mrad**	**0.84 mrad**
Q.E. @ 400nm	~0.24	~0.21
C.E.	~0.7	~0.95 (?)
Geometrical Efficiency with magnetic shields	~0.79	~0.62
QE*CE*GE	**~0.133**	**~0.124**
Ng per track (simulated)	**52.0**	**50.3**
Total s$_{q}$ per track	**0.115 mrad**	**0.118 mrad**

- MAPMTs and HPDs are expected to provide similar performance !
- We favor MAPMTs because of **cost**, magnetic field effects, HV and gain

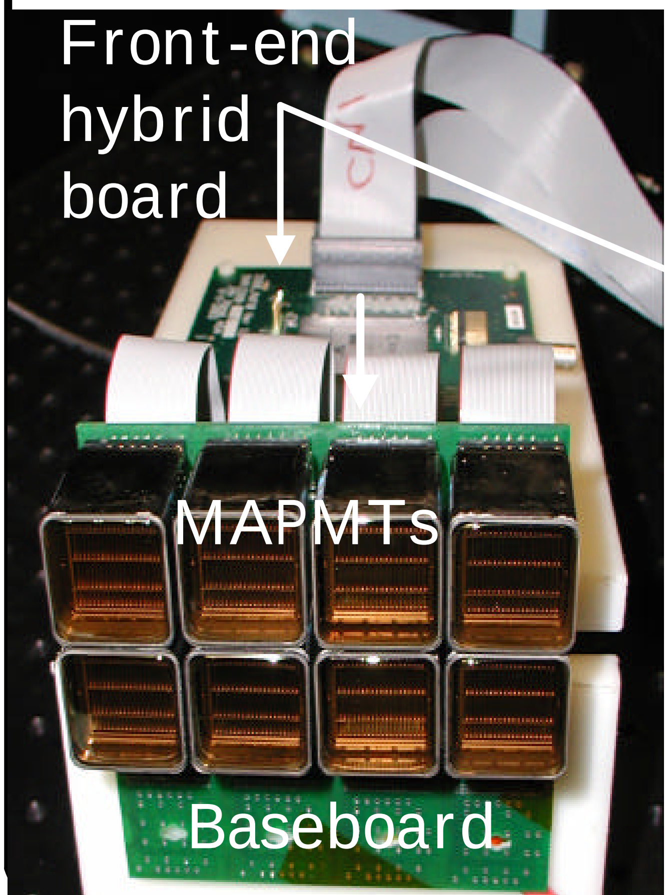
Gas RICH Test Beam Prototype





Preliminary readout chain

Advanced prototypes

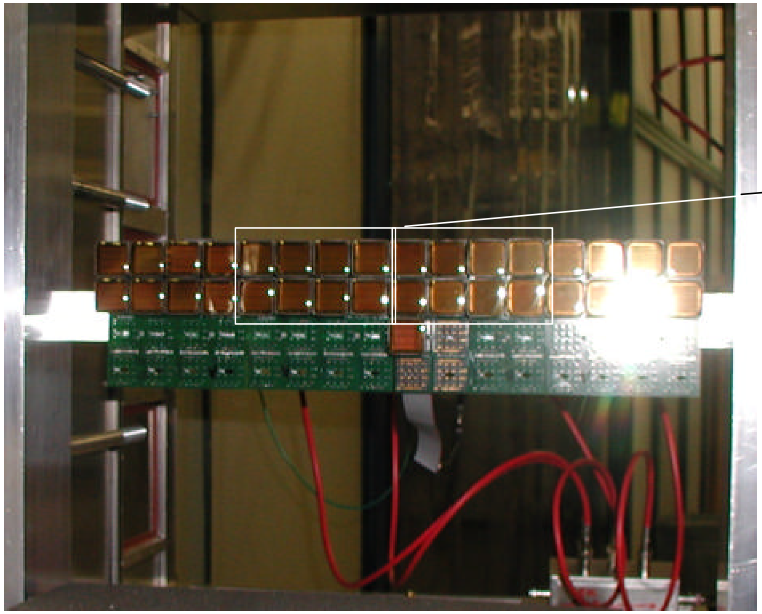


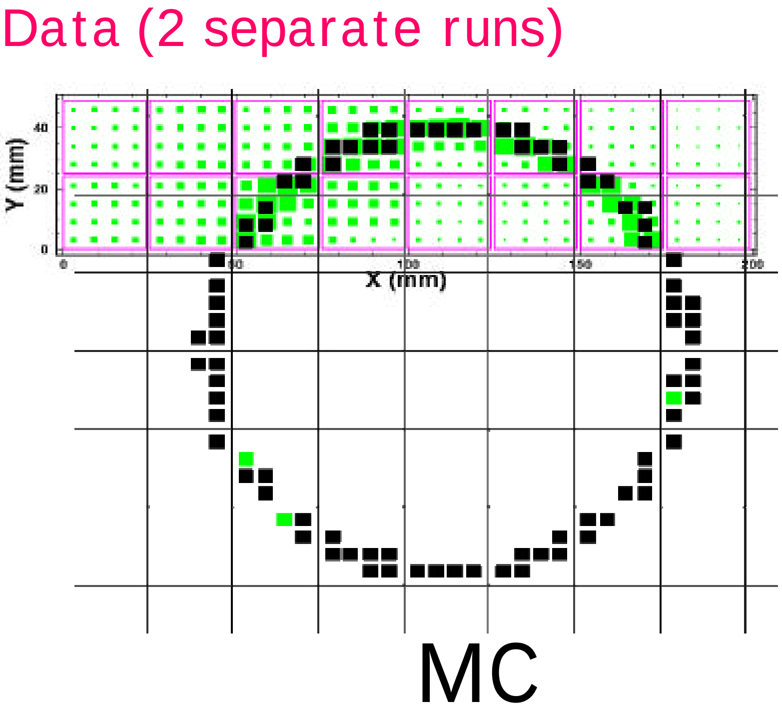
DAQ adopted from bench test system

- Limitations:
  - 128 channels (maximum of 8 MAPMTs readout at a time)
  - Could not be triggered on individual tracks (asynchronous trigger)

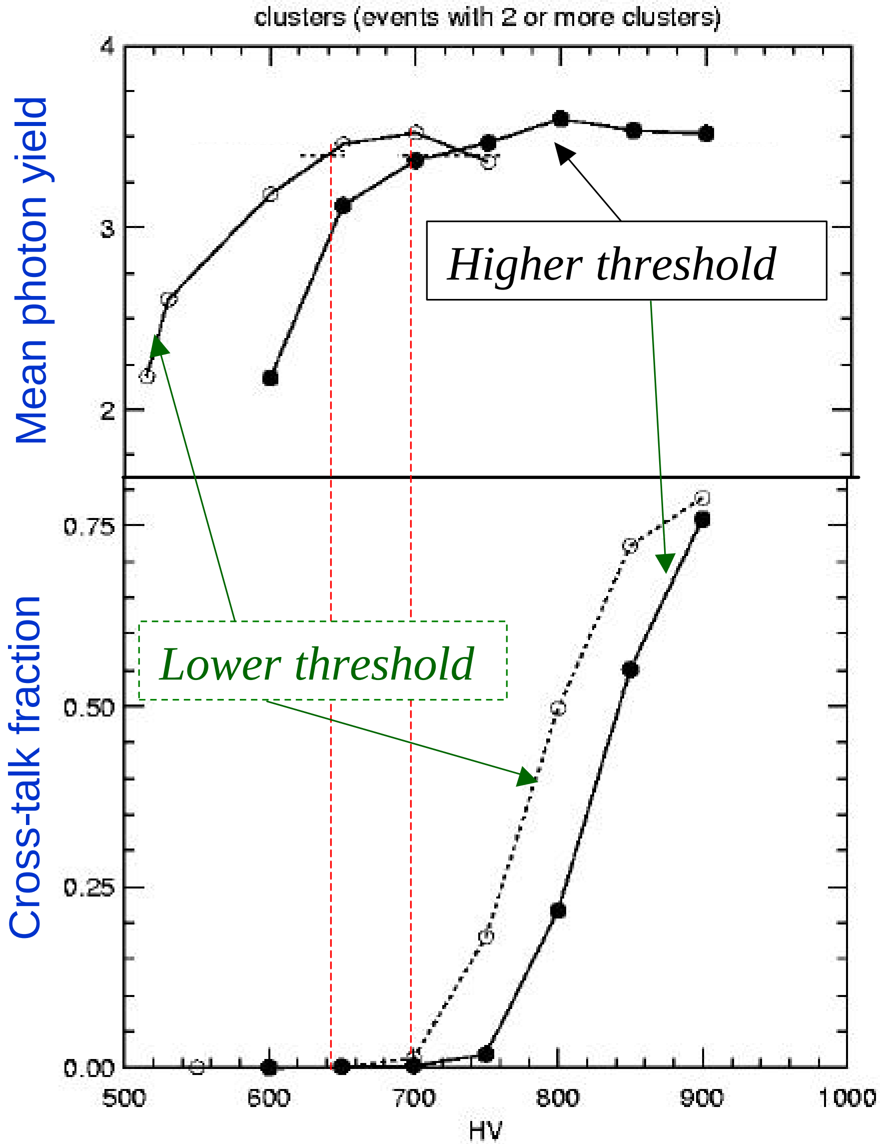
See talk by Marina Artuso for more details on development of readout electronics

Air radiator (actually Argon)





Finding operating point



The cross-talk appears to be related to the saturation of FE chip.

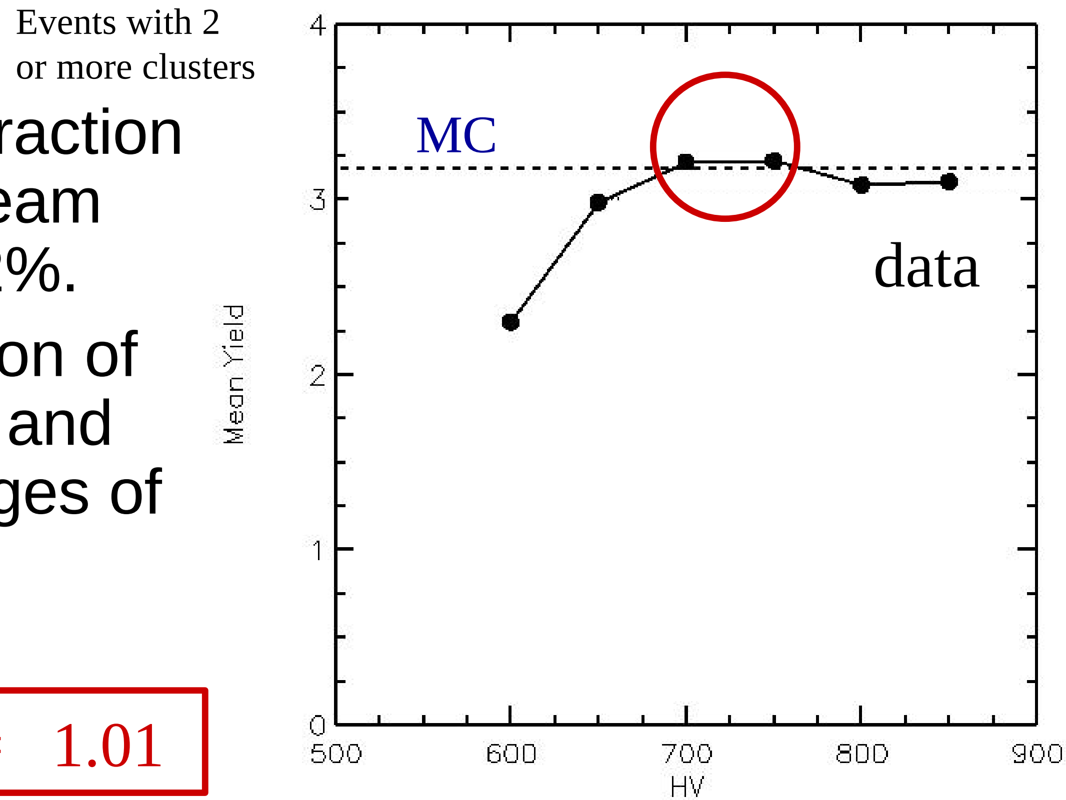
First ~50V of the plateau region coincides with the no cross-talk regime.

Next iteration of baseboards and FE electronics will broaden the operating point

(was discussed by M. Artuso)

Photon yield results (the air data)

- Multiple-track event fraction measured with the beam scintillators to be ~12%.
- MC included simulation of multiple-track events and light losses at the edges of the trigger window

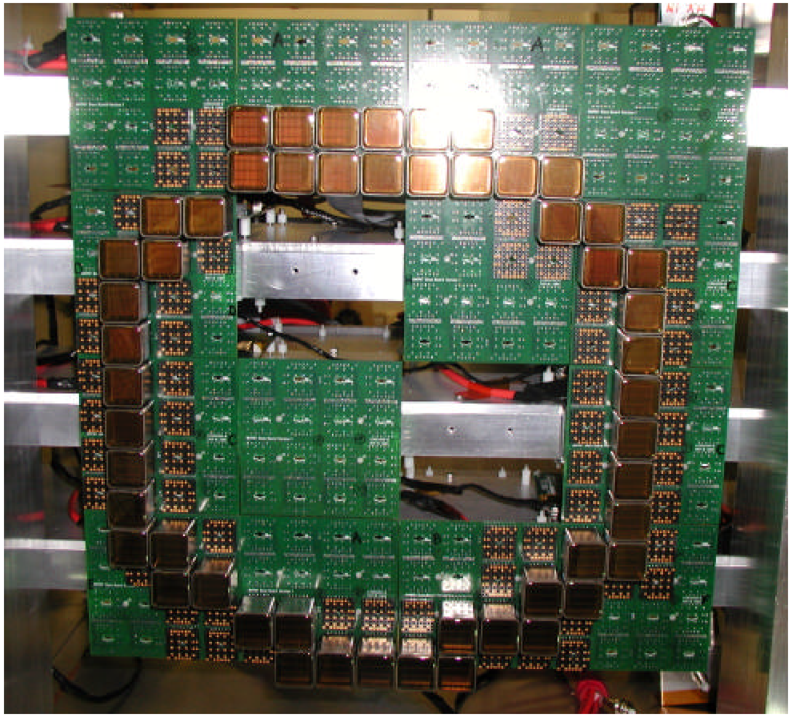


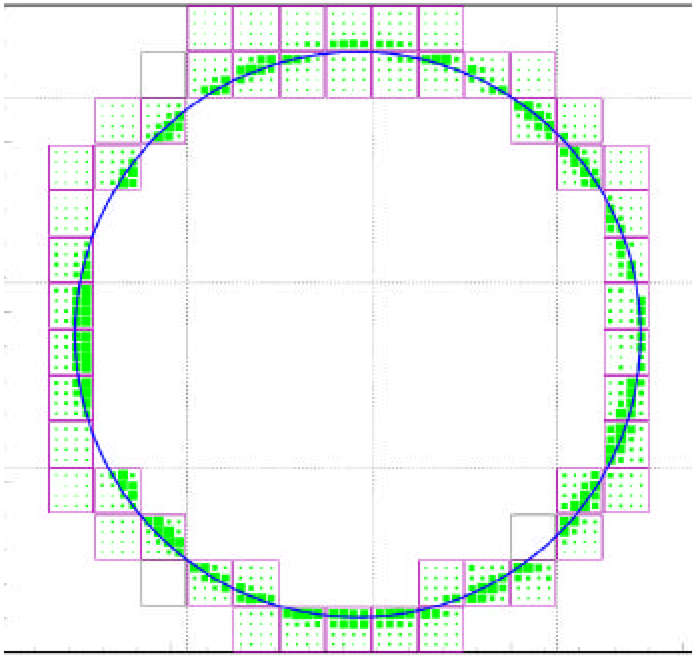
$$\boxed{\langle N\gamma\rangle_{data} / \langle N\gamma\rangle_{MC} = \quad 1.01}$$

Preliminary

- Q.E.*collection-efficiency of R8900 MAPMTs agrees with the expectations (encoded in the MC)
- No significant losses in FE readout (neglected in MC)

Test beam with C_4F_8O radiator



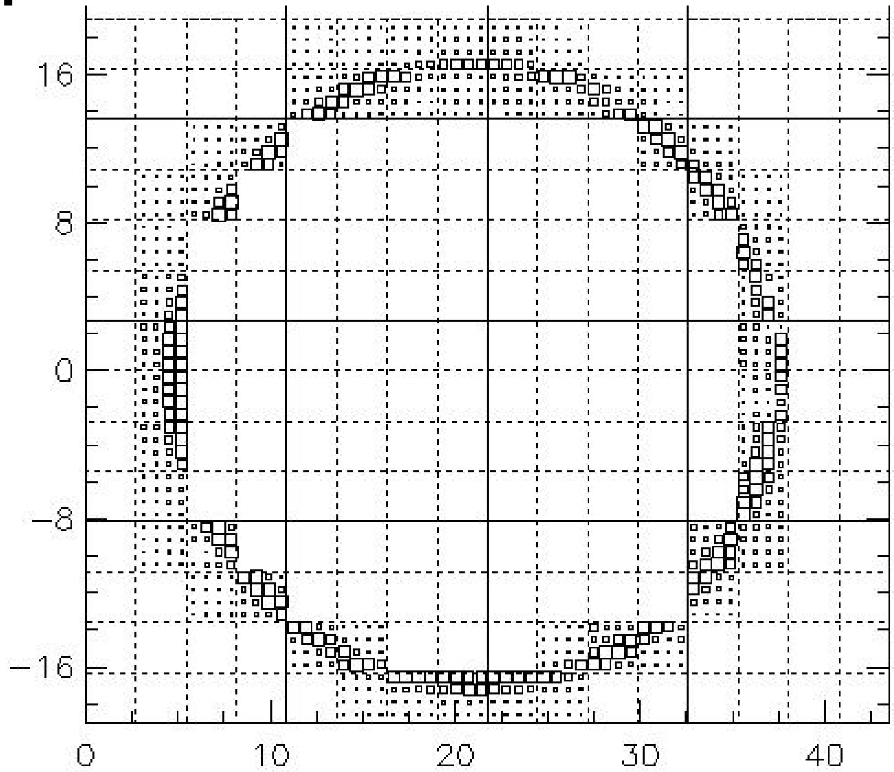


(superposition of 10 runs)

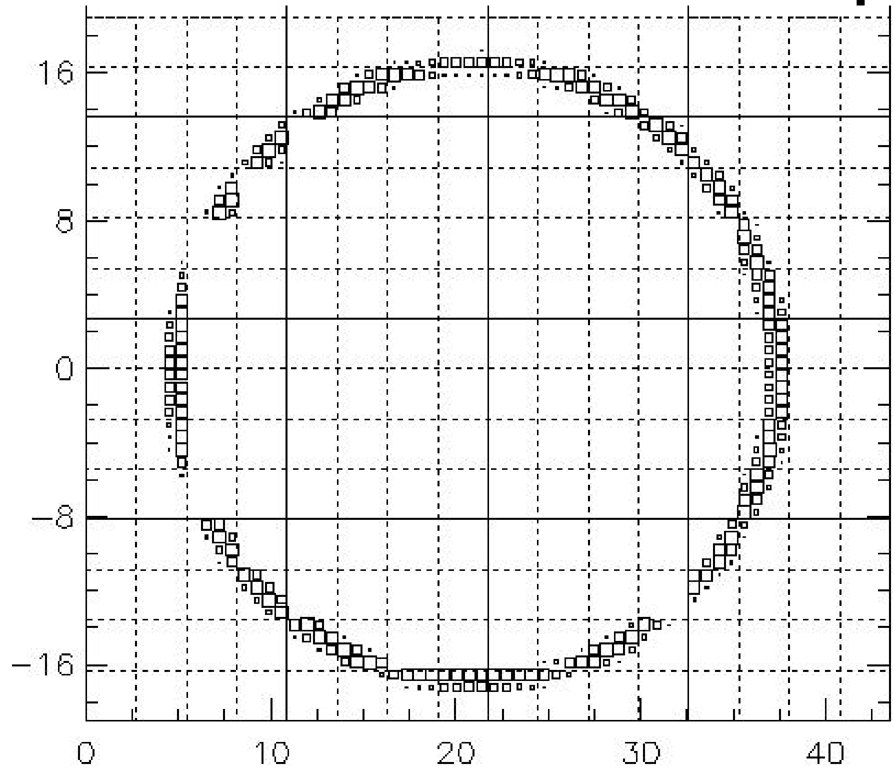
- All 52 MAPMTs deployed (we could read out up to 8 at a time)

Data vs MC

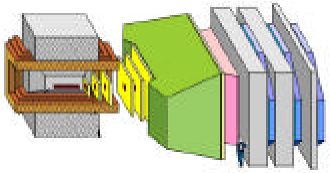
data



MC after minimization

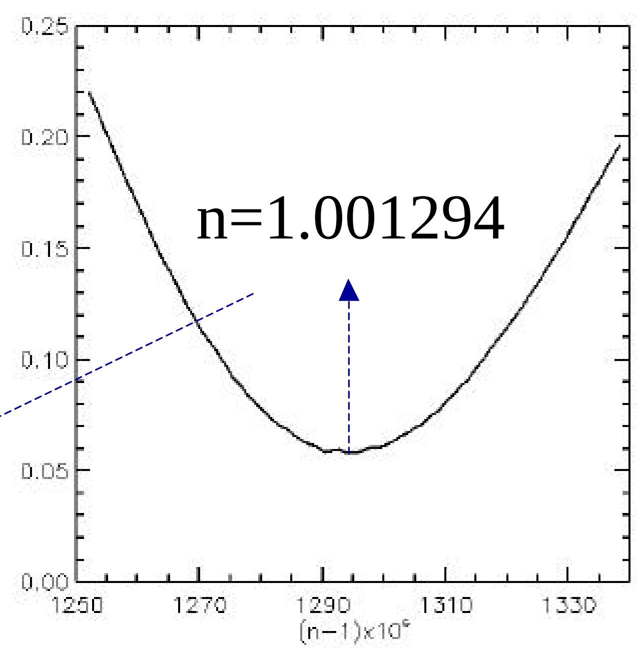


Ring intensity pattern well reproduced in MC



Refraction index from the test beam data

$$c^2 \equiv \sum_{i\,(pixels)} (I_i^{data} - I_i^{MC})^2$$



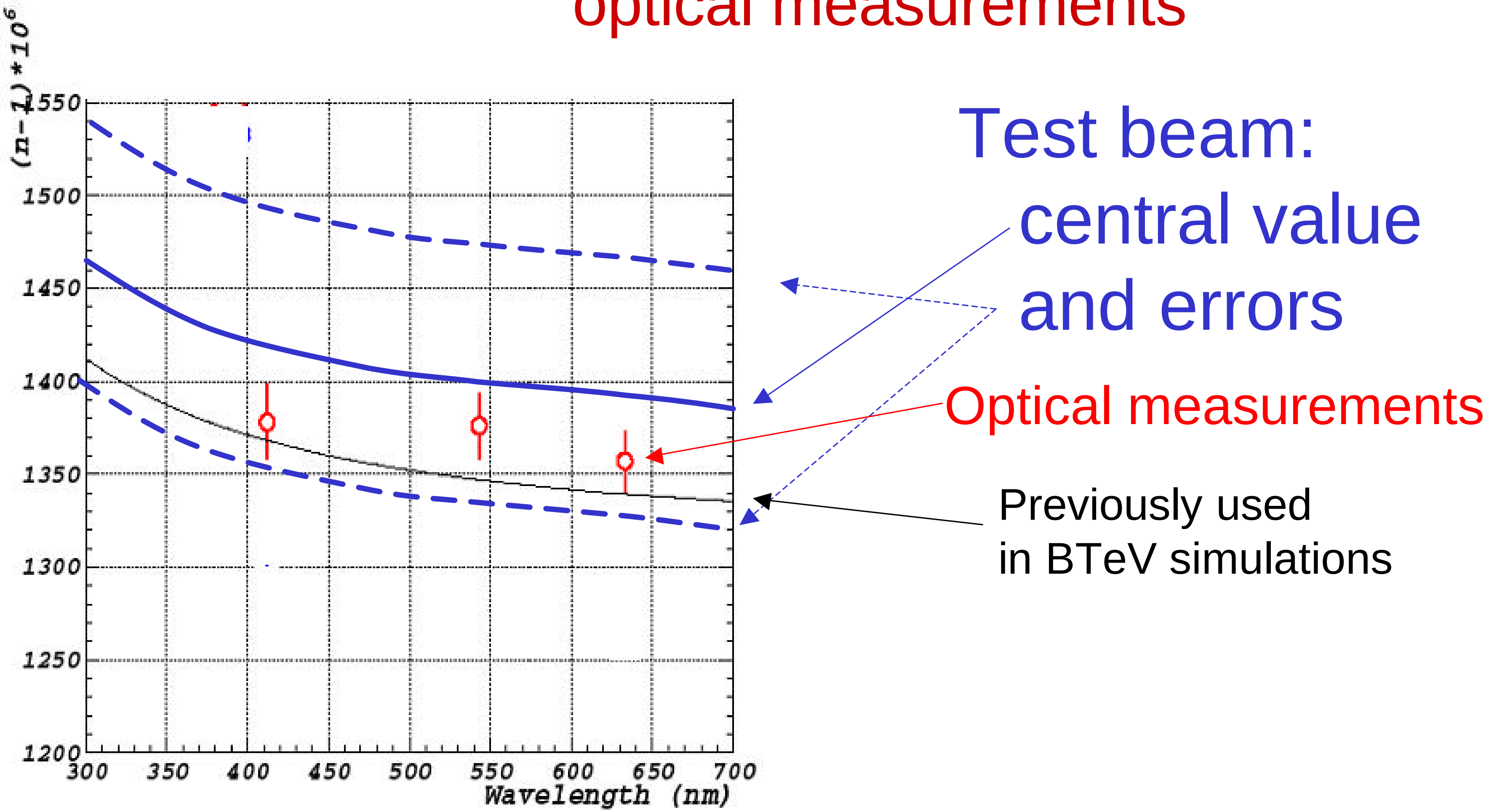
$$n_{measured} - 1 = \frac{P/T}{P_0/T_0}\Big((n_{C_4F_8O} - 1)\cdot(1 - f_{air}) + (n_{air} - 1)\cdot f_{air}\Big)$$

$(97 \pm 1)\%$ $(8 \pm 2)\%$

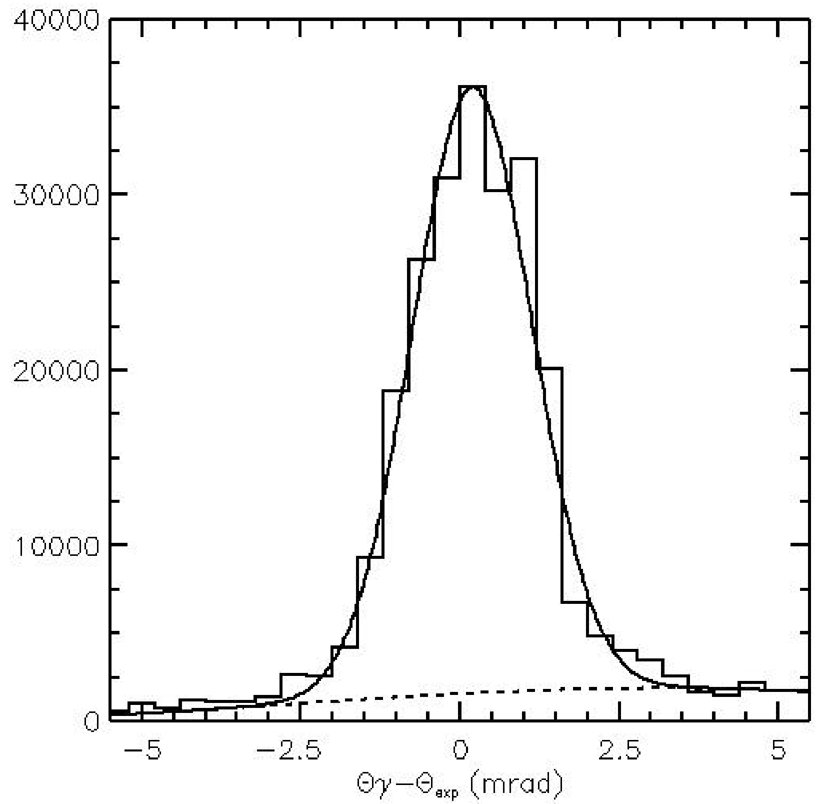
$$n_{C_4F_8O} = 1.001432 \pm 0.000071 \quad \text{(preliminary)}$$

$$(n_{proposal} = 1.001380)$$

Comparison to the optical measurements

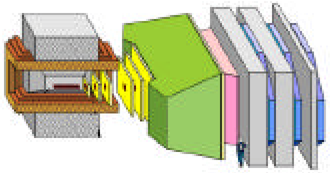


Cherenkov angle resolution (test beam)



$$\sigma_\gamma = 0.94 \text{ mrad}$$

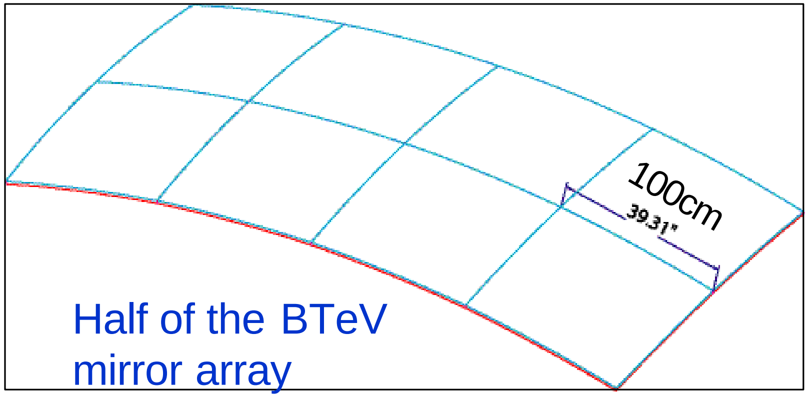
Larger than expected for BTeV (0.83mrad) because of non-neglible beam divergence and run-to-run changes of air fraction



Next test beam run

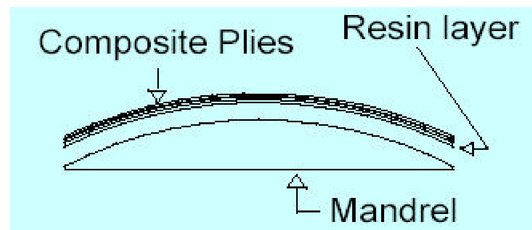
- New DAQ system with ability to readout all MAPMTs for each event
- New firmware allowing individual track trigger
- Reoptimized baseboards
- Expect to take data in Jan.05:
  - More robust measurements of photon yield and Cherenkov angle resolution
  - Next iteration in optimization of MAPMT/FE readout setting

Mirrors



Half of the BTeV mirror array

R~7m

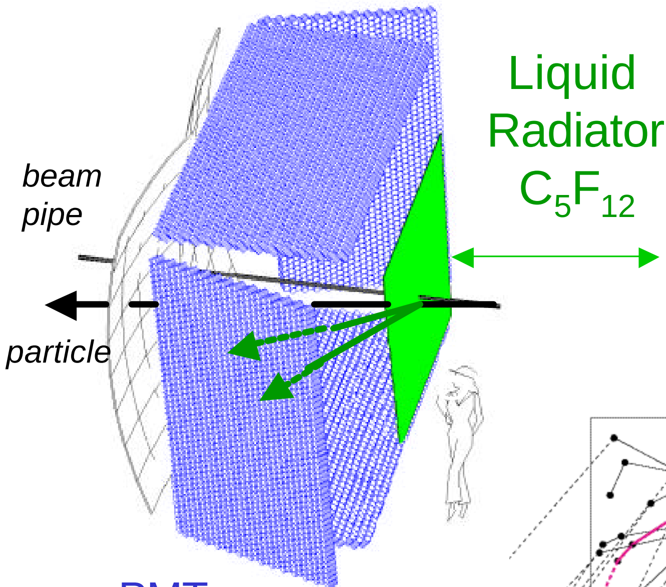


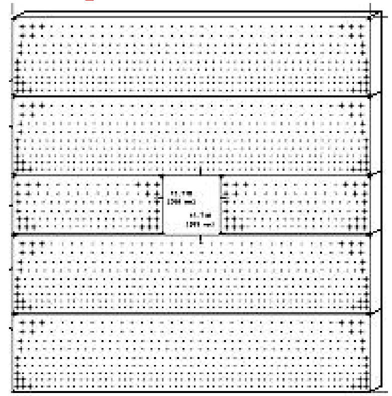
Recent prototype

30x30cm, R=3.5m

- CMA mirrors:
  - Large tiles (tile alignment less important)
  - Low radiation thickness 1-2% (helps EM calorimeter)
  - Lightweight (easy to support, don't distort under their own weight)
  - Excellent optical properties demonstrated by the company in the previous projects
- C_4F_8O compatibility:
  - Carbon Fiber layer not exposed to the gas (coated with epoxy)
  - No changes in spot size and radius observed for the prototype mirror exposed to C_4F_8O for a month (test will continue).

Liquid Radiator RICH



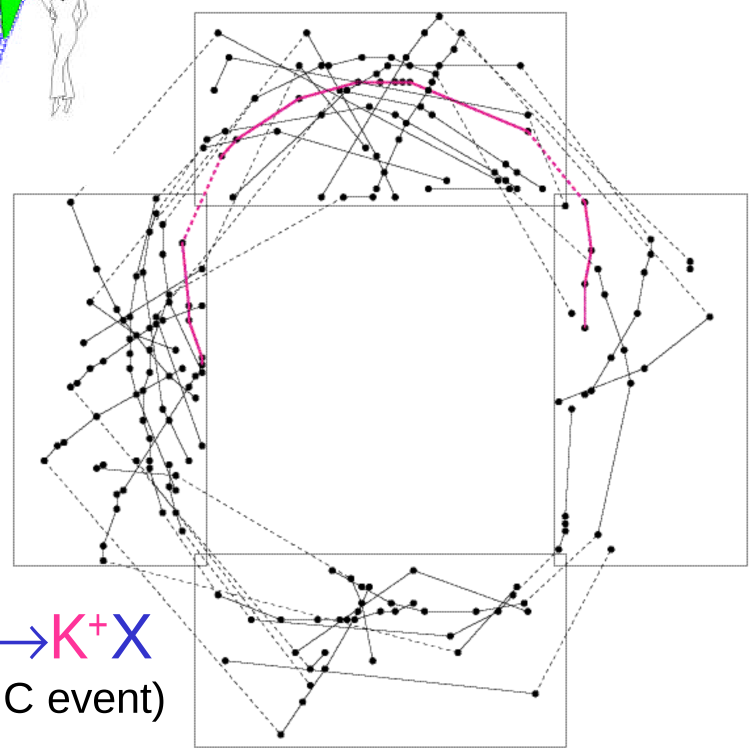


3 mm CF, **1 cm of C_5F_{12}**, 3 mm quartz
Structure is reinforced by CF posts.

Split into 5 volumes to reduce pressure.

Total material budget: $X_0 \sim 8.7\%$

Needed for K/p separation below 9 GeV



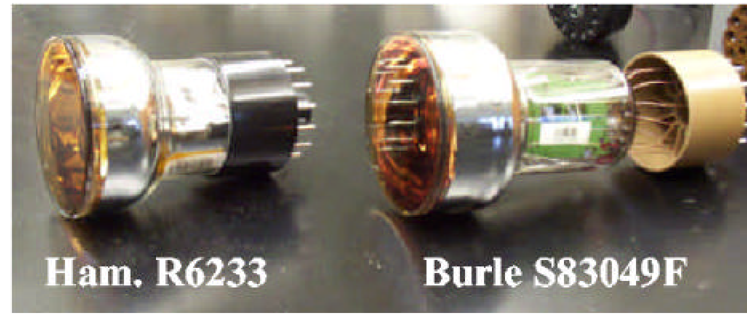
$B \rightarrow K^+X$
(MC event)

Expected performance

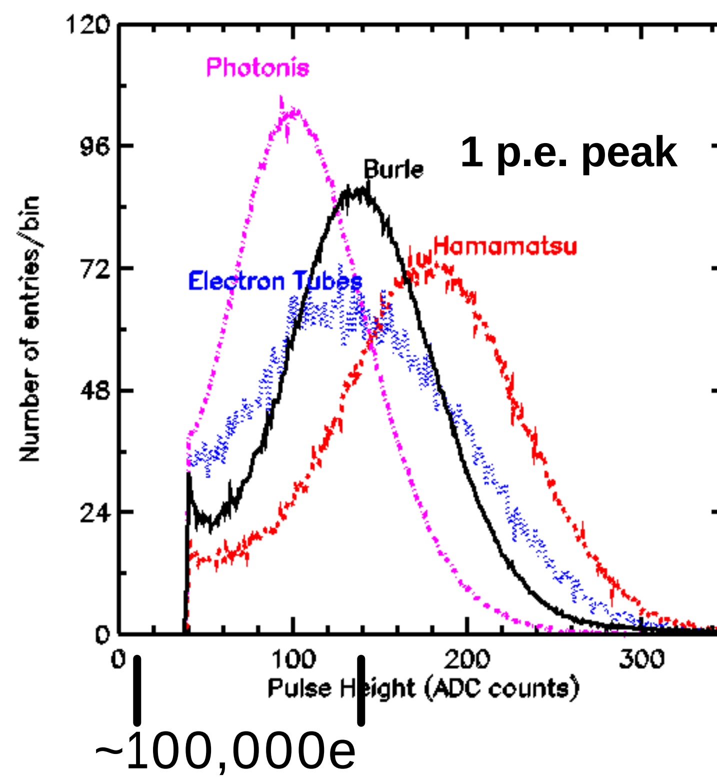
PMT size	3”
# of tubes	4948
Segmentation	5.3mrad
Chromatic	3.7mrad
Emission	0.4mrad
Total σ_θ per photon	6.2mrad
$N\gamma$ per track	12.4
Total σ_θ per track	1.8mrad

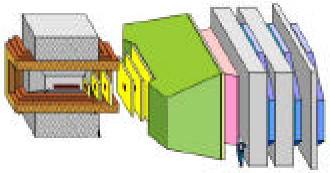
Photodetectors for the Liquid Radiator RICH

- Standard (single anode) 3” PMT:
  - Need about 5,000 tubes
  - 8-stage box dynode structure; gain ~10^5
  - Produced in mass quantities for medical applications



- We tested sample tubes from 4 manufacturers:
  - Burle, Electron Tubes, Photonis and Hamamatsu
  - All capable of detecting a single photon
  - Magnetic field sensitivity was determined (OK when shielded by mumetal tubes)
- Test beam in summer 2005





Conclusions

- Dual radiator RICH (mirror focused gas radiator + proximity focused liquid radiator) will provide excellent hadron identification and enhance lepton identification in BTeV
- C_4F_8O a suitable replacement for C_4F_{10} as gas radiator
- R8900-M16 MAPMTs are now the baseline photodetectors for the gas radiator:
  - Encouraging results from the initial test beam (more data to be collected)
- Construction phase to start next year. Photodetector acquisition in 2006-08. Start taking data in 2009.